Journal of The Palaeontological Society of India
Vol. 43, 1998, pp. 89-100

MICROSTRUCTURE AND MICROFABRIC STUDIES OF PALAEOPROTEROZOIC SMALL DIGITATE STROMATOLITES (MINISTROMATOLITES) FROM THE VEMPALLE FORMATION, CUDDAPAH SUPERGROUP, INDIA

MUKUND SHARMA and MANOJ SHUKLA

BIRBAL SAHNI INSTITUTE OF PALAEOBOTANY, 53 UNIVERSITY ROAD, LUCKNOW - 226007, UTTAR PRADESH, INDIA
E Mail bsip@bsip.sirnetd.ernet.in

ABSTRACT

Small digitate stromatolites (5-20 mm long) are present in carbonate units of the lower parts of the Vempalle Formation (Papaghani Group) of the Cuddapah Supergroup in Kadiri region, Anantapur district of Andhra Pradesh. The stromatolites are columnar and generally branched, slightly dendritic or umbellate, often without wall structure, and are mostly silicified (secondary silicification). Columns are cylindrical to turbinate with a rounded to lobate cross section 2 - 12 mm in diameter.

Two origins for the distinctive microstructure and microfabric have been discussed. The stromatolites have been interpreted as having a biogenic origin in which the microstructure of the stromatolite corresponds to the regular banded type. The microstructure is composed of dark lamellae of microbial mat and coarser light lamellae representing less pigmented portions of the microbial mats and consisting largely of precipitated carbonate minerals. Densely pigmented lamellae are microcrenuate. The fabric consists of almost parallel radial fibres that intersect the light and dark lamellae. Alternatively, the growth of radial fabric may be attributed entirely to chemogenic processes resulting from radial growth formed at an early stage of stromatolite formation. These stromatolites are considered to be formed in a peritidal environment in a shallowing upward sequence as represented by intraformational brecciated carbonate laminae and underlying oolites. This association may be one of the reasons for their smaller size.

Small stromatolites in India and other regions of the world (Australia, Canada and China) are noted to be characteristic of the upper part of the Palaeoproterozoic sequences. It is concluded that ministromatolites are characteristic of the Palaeoproterozoic (Orosirian) period and are supposed to be formed by cyanobacterial filaments. .

Key words: Ministromatolites, microstructure, Palaeoproterozoic, Cuddapah Supergroup.

INTRODUCTION

The origin and biogenicity of stromatolites is once again a matter of debate (Walter, 1996, Grotzinger and Rothman, 1996, Riding and Sharma, 1998) even though the occurrence of microfossils in associated chert, and occasionally in stromatolites, had convinced geologists about the biogenic nature of most of these structures. But miniature stromatolites, or ministromatolites as they are commonly known, have received much attention in recent years and various generic level taxa have been erected in different parts of the world (for a list see Grey, 1984).

Two distinct schools of thought prevail on the origin of these ministromatolites. One is supported by the palaeontologists who consider these stromatolites to be as of biogenic origin (Raaben, 1980, 1982; Liang *et al.*, 1984; Grey, 1984) and use them as biostratigraphic tools. The other school, belong to the sedimentologists, popularly known as the North American School, considers them to be sedimentological structures (Hoffman, 1975; Hofmann and Jackson, 1987; Grotzinger and Reed, 1983; Grotzinger and Rothman, 1996). Based on the similarity between fossil fabrics and modern tufa fabrics (Folk and Assereto, 1976; Kendall and Broughton, 1978; Handford *et al.*, 1984), Hofmann and Jackson (1987) concluded that the radial fibrous fabric of the ministromatolites could be a result of primary or very early diagenetic precipitation within or on the microbial mats. Direct precipitation of carbonate in the sea enabled tidal flats to prograde in gradual shallowing upward peritidal cycles of which the ministromatolites are characteristic (Grotzinger and Rothman, 1996).

Those associated with the taxonomy of stromatolites have considered these structures under

distinct hierarchial classification such as Microstromatolites (Raaben, 1980), Pseudogymnosolenidae (Liang *et al.*, 1983) or Pseudogymnosolenaceae (Liang *et al.*, 1984). In most of the Palaeoproterozoic and early Mesoproterozoic carbonate sequences such ministromatolites are abundant and characteristically confined to peritidal sequences or restricted evaporitic basin environments, (Cao, 1983; Grotzinger, 1986; Grotzinger and Reed, 1983; Grey, 1984; Grey and Thorne, 1985; Ricketts, 1983, Walter *et al.*, 1993). In Canada, ministromatolites occur in one Archaean and several early Proterozoic sequences (Hofmann, 1981). Grey (1994) reported similar ministromatolites from the Glengarry Group, Glengarry Basin, Western Australia and concluded that the stromatolites belonging to Orosirian period.

MATERIAL AND METHODS

The material discussed in the present paper is from slabs and thin sections of silicified biostromes deposited in intertidal to supratidal regimes of the Vempalle Formation. Most of the specimens figured in the paper are photographed with a Wild Heerbrugg Microscope. The specimens and slide illustrated in this paper are deposited in the BSIP repository and catalogued under BSIP specimen number 37750 - 37753 and BSIP slide number 11809 - 11812.

AGE AND SEDIMENTS

The age of the Vempalle Formation sediments containing these stromatolites has been inferred to be older than 1817 ± 24 million years based on Rb/Sr dating of a sill intruding the Papagahni and Chitravati groups which provides a minimum constraints on the sedimentation of these groups (Bhaskar Rao *et al.*, 1993). A Pb isotope dating on the stromatolitic carbonates suggests an age of 1759 ± 48 million years and represents a younger limit for sedimentation/diagenesis of dolomites of the Vempalle Formation (Zacharia *et al.*, 1996). Based on the Rb-Sr data Crawford and Compston (1973) suggested that the igneous rocks of the Cuddapah are older than 1550 million years and may be as old as 1700 million years. Earlier biostratigraphical studies of the stromatolites suggested an age of 1600-900 million years (Gururaja and Chandra, 1987).

CHARACTERISTICS OF MINISTROMATOLITES

Ministromatolites are variously described in the literature as *Pseudogymnosolen, Asperia, Yelma, Minicolumella, Liaohella, Parmites, Kotuikania,* and *Anbaria*. They have several morphological features in common and are known from several part of the world (Australia, Canada and China) and occur in Archaean to Palaeoproterozoic sediments. They dominate in the later part of the Palaeoproterozoic.

Common morphological features of these stromatolites include millimetric to centimetric, cylindrical to turbinate columns with erect to steeply inclined habit arising mostly from stratiform lamination. They have tuberculate to rugose outlines, generally no wall, rounded to lobate cross sections, and β type branching. Laminae are wavy to crinkled and are slightly to moderately convex. The degree of inheritance is high. They are generally dark coloured in comparison to the matrix.

In petrological section, the ministromatolites consist of thin, dark and thick, light lamellae; a feature characteristic of stromatolites. Alternating light and dark lamella show second to third order curvature resulting in a crinkled appearance. The lighter lamellae are submillimetric in thickness and are dominated by clear 50-150μm in diameter equant, xenotopic dolomite crystals. The darker lamellae are made up of equant xenotopic dolomite crystals 5-50μm in diameter with dispersed organic matter. Sometimes, it has been noted that a laminae is continuous in many erect columns. Dr. Kathleen Grey informs that "...This is a very typical characteristic of ministromatolites. It occurs in nearly every example I have seen. It is a good indicator of seasonal deposition in a closed environment such as a lake" (personal communication). Ministromatolites which are preserved in dolomites seldom show radial fibrous fabric, whereas those which are preserved in chert show well developed radial fibrous fabric.

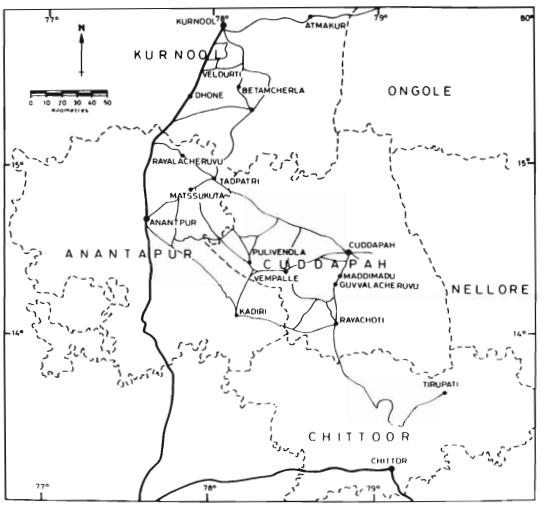


Fig.1. Schematic map showing the locality of stromatolites occurrences.

GEOLOGY AND PALAEOENVIRONMENT

The geology and sedimentological aspects of the Cuddapah Supergroup are discussed by Narayan Rao *et al.* (1987). Several stromatolites forms have been recorded from the Cuddapah Supergroup (for an inventory see Guruaja and Chandra, 1987). Small digitate ministromatolites occur in the Palaeoproterozoic Vempalle Formation of the Cuddapah Supergroup in the Kadiri area of Anantpur district, Andhra Pradesh (fig. 1). Most of the forms are silicified and some are dolomitized with well developed radial fibrous fabric. This fabric resembles the biofabric of extant cyanobacteria, such as *Rivularia* and *Phormidium* (see Monty, 1976; Monty and Mas, 1981) suggesting an analogue for the origin of the Palaeoproterozoic ministromatolite fabric. However, petrological study of the fabric also suggests that precipitative mechanisms may be involved in the formation of this fabric.

MICROSTRUCTURE AND MICROFABRIC

Most of the specimens studied under the present study are silicified, submillimetric to millimetric columns forming small digitate bushy fascicles with erect, slender, subparallel, closely spaced columns. Branching is infrequent, if present, and of - β style. Columns arise from stratiform laminae or dome shaped bases. Wall structure is absent or poorly preserved (Pl. I, figs.1-3; Pl. II, figs. 1, 3 & 5; Pl. III, fig. 1). The cross section is rounded to lobate (fig.3; Pl. I, fig. 4). Column margins are bumpy, laminae are rounded, convex to flat and often wavy or crinkled. The microstructure is regularly banded (Pl. III, fig.4) and shows cyclic development of laminae, and pseudocolumnar development.

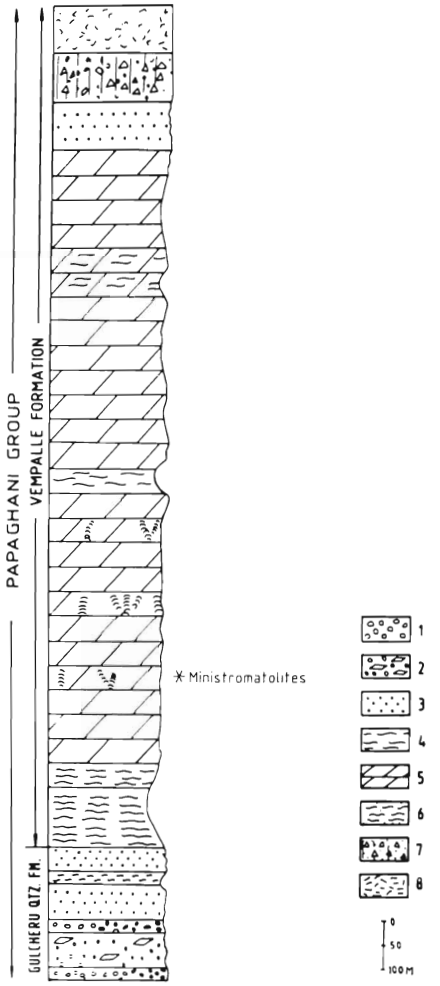


Fig.2. Lithostriatigraphic succession of the Papaghani group of the Cuddapah Supergroup and principal horizons containing stromatolites. 1= conglomerate; 2= arkose; 3= quartzite; 4= shale; 5= dolomite; 6=sahle mudstone; 7= chert breccia; and 8= basic flow.3 possiblearya

The microstructure of the laminae is well preserved in fine grained chert and can be best observed under a low power microscope. It is dominated by the usual light and dark laminations

(Pl. II, figs. 2, 4 & 6; Pl. III, figs. 2 & 3). The light laminae are thicker and the darker laminae are micrometric. The fine-grained, dark carbonate laminae correspond to the densely pigmented laminae of the microbial mat whereas the coarse grained carbonate laminae correspond to a less pigmented region. The diffrential preservation of the biofabric is probably the result of the biomass present at the site of deposition. The other constituent is a radial fibrous fabric surrounded by a dark pigmentation layer which cannot be further resolved. The radial elements are parallel and rectilinear in longitudinal section (Pl. III, figs. 5-7), and are rounded to polygonal in cross section (Pl. I, fig. 4). In each column, the radial fabric intersects the dark pigmentation layer orthogonally. Individual fibrous elements are 2-5μm wide and extend across several light and dark laminae. The dark pigmented laminae are 10 - 100μm. Some of the fibres are unequal and abundantly terminate below the dark lamellae. Each successive dark laminae is presumably a product of accretionary growth which is subsequently remobilised during silicification to produce the diffuse outline. In the intercolumnar spaces, the fibres radiate downward to star-like projections in all directions. In some places, dolomite ghosts are present, suggesting that the radial fabric was replaced by idiotopic dolomite before silicification. Similar radial fabric is also present in stratiform regions of the mats. Intersection of such fabric with the dark and light lamellae is observed only at the margins.

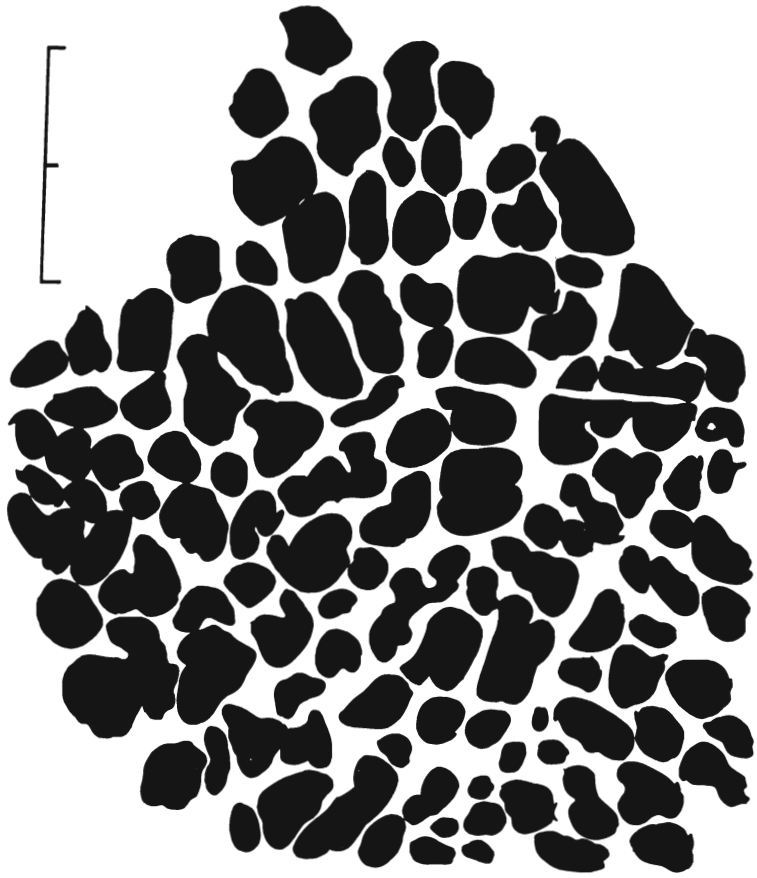


Fig.3. Diagrammatic representation of plan cross section of ministromatolite. Note the rounded and the lobate cross-section (Scale = 2 mm).

ORIGIN OF RADIAL FIBROUS FABRIC

The origin of radial fibrous fabric in ministromatolites of the Palaeoproterozoic age has been considered to be either the product of biogenic processes (Raaben, 1980, 1982; Liang *et al.*, 1984; Grey, 1984) or abiogenic processes (Hoffman, 1975; Hofmann and Jackson, 1987; Grotzinger, 1993; Grotzinger and Reed, 1983; Grotzinger and Rothman, 1996) or a combination of both the processes. Petrographic studies of the fabric helps in assessing their origin.

Biogenic origin: The comparison of radial fabric with fabrics of extant stromatolites provides some indication than it may be a product of biogenic activity. Monty (1976) showed that the fabric formed by the *Rivularia* and *Phormidium* in modern stromatolites is similar to that of ministromatolites. Even in the Lower Palaeozoic *Palaeoleptophycus* forms a similar fabric (see Orlov, 1963). In modern stromatolites the fabric is formed by cyanobacterial mat bundles. And it is possible that the Lower Palaeozoic fabric also represents a fossilized cyanobacterial colony. The darker lamellae of the stromatolites may possibly represents stress conditions resulting in the excessive pigment secretion. A biological interpretation is further supported by the silicified *Pseudogymnosolen* from the Mesoproterozoic of Wumishan Formaion of northern China. These ministromatolites contain straight, vertical tubes which are interpreted as tubes left by degraded cyanobacterial sheaths (Cao, 1983, p. 6 pl. l, fig. 5). Unequivocal microfossils were reported by Cao (1983) in *Pseudogymnosolen condylose* Liang from the Wumishan Formation. The monospecific microfossils, assignable to a filamentous oscillatoriaceae *Eomycetopsis* sp. are recorded in ministromatolitic laminated layers of *Pseudogymnosolen*, which occasionally contains a few thick filaments? *Animikia* (Cao, 1991). It has been noted that filamentous mat of *Lyngbya, Phormidium* and *Plectonema* cyanobacteria types are commonly oriented vertically and define the primary fenestrae (Sergeev *et al.*, 1994). Comparing the ministromatolites of the Cuddapah Supergroup with those of the Wumishan Formation suggests that both could be considered biogenic in origin. However so far no fossilized microbial remains have been reported in the Cuddapah ministromatolites and this fact limits our interpretation of their being conclusively biogenic origin.

Abiogenic origin: The other possible interpretation of radial fibrous fabric origin is by abiogenic formation specifically as a result of a the chemogenic process producing from radial growth of a fibrous mineral, most likely aragonite or calcite. The mineral aggregate was subsequently replaced by silica without any destructive effects on the morphology of the acicular outlines. This fabric can be compared with chemogenically produced carbonate crust growth (Purser and Loreau ,1973, p.368), fibrous carbonate in chemogenic ooids and pisoids (e.g., Lebedev, 1967, p. 18-33; Bathurst 1971, p.306-307), aragonite cements (e.g., Scholle and Kinsman, 1974, fig. 5C, D; Loucks and Folk, 1976, fig.2-5; Folk and Assereto 1976, fig.8; Ginsburg and James, 1976, fig.5; Handford *et al.*, 1984, fig. 2f; Grotzinger and Reed 1983, fig. 1) and speleothems (e.g., Kendall and Broughton 1978, fig. 1-4, Tharaikill, 1976). Calcareous precipitates associated with surface streams may also form tufa-like structures (Braithwaite, 1979, fig. 2d). The pattern of truncation and interruption is more akin to that of the growth pattern of acicular crystals. The other argument put forward in favour of an abiogenic origin of this fabric is the angulate termini and polygonal cross section of some fibres or bundles. However, these features can be interpreted as either biogenic or abiogenic as the structures are similar to a group of structures reported from China and referred to the red algal group Manicosiphonoaceae (Cao and Zhao, 1978). Hofmann and Jackson (1987, p.969. fig.4A) compared the fabric with the nonbiogenic growth structures described by Kendall and Broughton, 1978, fig. 7a, 8 with plate 9, fig.4, or Cao and Zhao, 1978).

Most of the structures mentioned above are abiogenically formed. Stromatolites are known to have formed by the precipitation of calcium carbonate around algal filaments which look like mould growing in calcium rich streams (Crowe *et al.*, 1978). However, contrary to this type of formation, the ministromatolites of the Vempalle

Formation have rounded, lobate cross sections which are characteristics of biogenic origin.

DISCUSSION

The level of preservation of radial fibrous fabric suggests that it was formed at an early stage in the formation of ministromatolites. The fibrous layers could have been precipitated like the aragonite cement of salinas. It may have been precipitated either on the mat surfaces or was possibly biologically mediated by the mineralization of the surface. The low synoptic relief suggests that the stromatolites formed low protuberances that served as the nuclei for future mat or mineral crust formation. Other mineral precipitation kept pace with accretion allowing continuous formation of ministromatolites.

Other similar ministromatolites such as *Pseudogymnosolen, Asperia, Yelma* (now a junior synonym of *Asperia* in Grey, 1994), or *Liaoheella* may lack a radial fibrous fabric but the presence of mosaic dolomite suggests that they originally had such a fabric. Interestingly, most of these stromatolites show radial fibrous fabric when preserved in chert. It is now generally accepted that the interplay of environmental and biological influences determines the form and fabric of stromatolites (e.g., Walter, 1977; Semikhatov *et al.*, 1979, Burne and Moore, 1987). In the specimens described by the Grey and Thorne (1985) and in the examples illustrated by Monty (in Walter, 1976), the fabric is formed in the following manner: At the periods of maximum biogenic activity (which may be a response to day light or to a change in season), the filaments grow vertically and push upwards through accumulated sediments or precipitated gel. This typically occurs in photosynthetic cyanobacteria that move towards light. When environmental conditions are unfavourable (night - time, adverse seasonal conditions such as cold weather or desiccation), the filaments assume horizontal positions. These horizontal filaments form the dark layer. This also explains why light laminae are commonly thicker than dark laminae.

Dense, dark pigment production may be attributed to the need to offset the increased environmental stress, e.g., probably long exposures to air, shallow water or prolonged UV radiation or insolation. It is probably the presence of aragonite which due to diagenesis is arrested early by silicification. It is concluded that the almost similar constituent can produce two different types of fabric depending on the preservation. The radial fibrous fabric noticed in ministromatolites may be the result of the early silicificaiton of carbonate minerals. It is possible that the original fabric has been superimposed by subsequent diagenesis and silicification, and rectilinear morphological features may not be a true reflection of the radial fabric of the organisms involved in the formation of ministromatolites. Since no microfossils have been reported from the ministromatolites of the Vempalle Formation, which is affected by recrystallisation, the biogenic nature cannot be conclusively proved, although the dark pigmented laminae were present at the time of stromatolite formation.

Indirect evidence and close association of other stromatolite types (Gururaja and Chandra, 1987), and the presence of microbial remains in the cherts of the Vempalle Formation (Schopf and Prasad, 1978) are reasonably a sufficient evidence to consider these ministromatolites to be a product of biogenic structures. The occurrence together of mosaic dolomite and silicified radial fibrous fabric suggests that the original fabric was also fibrous.

The dominance of rounded to polygonal outlines over the angulate truncation in the Cuddapah ministromatolites supports the interpretation that radial bundles formed are after organic mats rather than the abiogenic origin as rectlinear elements as has been suggested for Belcher ministromatolites (Hofmann and Jackson 1987). The small number of angulate truncations may be the diagenetic alteration product.

CONCLUSION

The study of ministromatolites of the Cuddapah Supergroup emphasises following salient features.

1. Ministromatolites are abundant in the Vempalle Formation of the Cuddapah Supergroup, as they are in other Palaeoproterozoic sequences of the world.

2. Ministromatolites described in the literature commonly have radial fibrous fabric.
3. The cross section of these stromatolites range from rounded to polygonal which help in interpretation of their origin or biogenic/ biogenically mediated precipitation of carbonates. Rarely angulate cross section has been observed.
4. From the evidences presently available and by analogy with similar forms of China, the indications are that ministromatolites are biologically formed structures. However, biologically mediated precipitation of structures seems the most likely process of formation.
5. A fabric study of the Cuddapah stromaolites helps in the interpretations of accretion of stromatolites.
6. These biostromes were formed in salina margins as is evident from the textures of the ministromatolites.

ACKNOWLEDGEMENTS

Mukund is thankful to Dr. M.R. Rao (NGRI) for introducing to the field and acknowledges the help received from Dr. Kathleen Grey in improving the manuscript. The text of this paper has improved from the comments of an anonymous reviewer. We are grateful to the Director, BSIP for extending the facilities to complete this study.

REFERENCES

Bathurst, R.C. 1971. *Carbonate sediments and their diagenesis. (Developments in sedimentology)* **12**. Elsevier, Amesterdam.

Bhaskar Rao, Y.J. Pantulu, G.V.C., Reddy, V.D. and Gopalan, K. 1993 Rb-Sr evidence for 1800 Ma younger limit to early sedimentation in Proterozoic Cuddapah basin, southern India, p. 445-447. In Sixth National Symposium on Mass Spectrometery Preprint Volume Dehradun.

Braithwait, C.J.R. 1979. Crystal textures of recent fluvial pisolites and laminated crystalline crust in Dyfed. South Wales. *Jour. Sed. Petrol.* **49**: 181-194.

Burne, R.V. and Moore L.S. 1987. Microbialites: Organosedimentary deposits of benthic microbial communities. *Palaios.* **2**: 241-254.

Cao, R.J. 1983. Microflora of Precambrian - influences on stromatolitic morphology. *Bull. Nanjing Inst. Geol. Paleont., Academia Sinica,* **6**: 1-7.

Cao, R-J. and Jhao, W-J. 1978. The algal flora of the Tongying Formation (Upper Sinian System) in southwestern China. *Mem. Nanjing Inst. Geol. Paleont. Academia Sinica.* **10**: 1-40. (In Chinese with English abstract.)

Crawfod, A.R. and Compston, W.Q. 1973. The age of the Cuddapah and Kurnool System. South India. *Jour. Geol. Soc. Australia,* **19**: 453-464.

Crowe, R.W.A., Yeates, A.N. and Grey, K. 1978. Living stromatolites in the northern Great Sandy Desert, Western Australia;: a modern analogue for probable Tertiary deposits in the area. *West. Australia Geol. Survey Ann. Rep.* 1977: 73-75.

Folk, R.L. and Assereto, R. 1976. Comparative fabrics of length slow and length fast calcite and clacitized aragonite in a Holocene speleothem. Carlsbad Caverns, New Mexico. *Jour. sedim. Petrol.* 46: 466-496.

Ginsburg, R.N. and James, N.P. 1976. Submarine botrvoidal aragonite in Holocene reef limestone, Belize. *Geology,* **4**: 431-436.

Grey, K. 1984. Biostratigraphic studies or stromatolites from the Proterozoic Earaheedy Grouy, Nabberu Basin, Western Australia. *Bull. Geol. Surv. Western Australia,* **130**: 130 pp.

Grey, K. 1994. Stromatolites from the Palaeoproterozoic (Orosirian) Glengarry Group, Glengarry Basin, Western Australia. *Alcheringa,* **18**: 275-300.

Grey, K. and Thorne, A.M. 1985. Biostratigraphic significance of stromatolites in upward shallowing sequences of the Early Proterozoic Duck Creek Dolomite, Western Australia, *Precamb. Res.* **29**: 163-206.

Grotzinger, J.P. 1986. Cyclicity and palaeoenvironmental dynamics, Rocknest platform, northwest orogen, northwest Canada. *Bull. Geol. Soc. Amer.* **97**: 1208-1231.

Grotzinger, J.P., and Reed (=Read), J.F. 1983. Evidence for primary aragonite precipitation. Lower Proterozoic (1.9 Ga) Rocknest dolomite. Wopmay orogen, northwest Canada. *Geology,* **12**: 710-713.

Grotzinger, J.P. and Rothman, D.H. 1996. An abiotic model for stromatolite morphogenesis. *Nature,* **383** : 423-425.

Gururaja, M.N. and Chandra, A. 1987. Stromatolites from Vempalle and Tadapatri Formations of Cuddapah Supergroup (Proterozoic) Andhra Pradesh and their significance. *Mem. Geol. Soc. India,* **6**: 399-427.

Handford, C.R., Kendall, A.C,. Prezbiondowski, D.R., Dunham, J.B. and Logan, B.W. 1984. Salina margin tepees, pisoliths, and aragonite cements, Lake Macleod, Western Australia: their significance in interpreting ancient analogs. *Geology,* **12**: 523-527.

Hoffman P. 1975. Shoaling upward shale to dolomite cycles in the Rocknest Formation (Lower Proterozoic), Northwest Territories, Canada, p. 257-265. In: *Tidal Deposits* (Ed. Ginsburg, R.N.), Springer-Verlag, New York.

Hofmann, H.J. 1975. Stratiform Precambrian stromatolites, Belcher Islands, Canada : relations between silicified microfossils and microstructures. *Am. Jour. Sci.* **275**: 1121-1132.

Hofmann, J. 1981. Precambrian fossils in Canada - the 1970s in retrospect, p. 419-443. In: *Proterozic Basins of Canada* (Ed . Campbell, F.H.A.), *Pap. Geol. Surv. Canada.*

Hofmann, H.J. and Jackson, J.D. 1969. Precambrian (Aphebian) microfossils from Belcher Islands, Hudson Bay. *Can. Jour. Earth Sci.* **6**: 1137-1144.

Hofmann, J. and Jackson, J.D. 1987. Proterozoic ministromatolites with radial fibrous fabric. *Sedimentol.* **34**: 963-971.

Kendall, A.C. and Broughton, P.L. 1978. Origin of fabrics in speleothems composed of columnar calcite crystals. *Jour. Sedim. Petrol.*, **48**: 519-538.

Lebedev, L.M. 1967. *Metacolloids in endogenic deposits.* Plenum Press. New York.

Liang, Y., Cao,. R-J., Zhang, L., Qiu, S., Xiao, Z., Du, R., Cao, R-G., Bu, D., Zhu, S., and Gao, Z. 1983. On the pseudogymnosolenidae of Late Precambrian in China. *Bull. Chinese Acad. Geol. Sci.* **6**: 125-130. (In Chinese. With English abstract.)

Liang, Y., Cao, R-J., Zhang, L.,Qiu, S., Xiao, Z., Cao, R-G., Duan, J., Du, R. M, Bu, J., and Gao, Z. 1984. On Pseudogymnosolenacea of Late Precambrian of China. *Scien. Sin.* **27**(5): 534-546.

Locus, R.G. and Folk, R.L. 1976. Fan like rays of former aragonite in Permian Captain Reef pisolite. *Jour. sedim. Petrol.* **46**: 483-485.

Monty, C.L.V. 1976. The origin and development of cryptalgal fabrics, p. 193-249. In: *Stromatolites* (Ed. Walter, M.R.), *Developments in Sedimentology*, **20**. Elsevier, Amsterdam.

Monty, C.V. and Mas, J.R. 1981. Lower Cretaceous (Wealdian) blue green algal deposits of the province of Valenia, eastern Spain, p. 85-120. In: *Phanerozoic Stromatolites* (Ed. Monty, C.), Springer-Verlag, Berlin.

Narayan Rao, B.K., Rajurkar, S.T., Ramalingaswamy, G. and Ravindra Babu, R. 1987. Stratigraphy structure and evolution of Cuddapah basin, p. 375-38. In : *Purana Basins of Peninsular India (Middle to Late Proterozoic). Mem. Geol. Soc. India*, Bangalore 6.

Orlov, You.A. (Ed.) 1963. Osnovy paleontologii. 14 Izdatel' stvo Akademii Nauk SSSR. Moscow.

Purser, B.H. and Loreau, J.P. 1973. Aragonitic, supratidal encrustations on the Trucial Coast, Persian Gulf, p. 343-376. In: *The Persian Gulf* (Ed. Purser. B.H.), Springer - Verlag, Heidelberg.

Raaben, M.E. 1980 (1982). Midrostromaity - Kharakteryi elent nizheneproterozoyskogo stromatolitovogo kompleksa. Dokl.., *Akad. Nauk S.S.S.R.* 250(3):734-738. (English Translation 1982, **250**: 123-136.)

Ricketts, B.D. 1983. The evolution of a Middle Precambrian dolostone sequence - a spectrum of dolomitization regimes. *Jour. Sedim. Petrol.* **53**: 565-586.

Riding , R. and Sharma, Mukund. 1998 Late Palaeoproterozoic (~1800-1600 Ma) stromatolites, Cuddapah Basin, southern India: cyanobacteria or other bacterial microfabric? *Precamb. Res.* **92**: 21-35.

Scholle, P.A. and Kinsman, D.J.J H. 1974. Aragonitic and high - Mg calcite caliche from the Persian Gulf - a modern analog for the Permian of Texas and New Mexico. *Jour. Sedim. Pertol.* **44**: 904-916.

Schopf, J.W. and Prasad, K.N. 1978. Microfossils in *Collenia*-Like stromatolites from the Proterocoic Vempalle Formation of the Cuddapah Basin, India. *Precamb. Res.* **6**: 347-366.

Sergeev, V.N. Knoll, A.H. and Grotzinger, J.P. 1994. Palaeobiology of the Mesoproterozoic Billyakh Group. Anabar Uplift. Northern Siberia. *Mem. Paleontol. Soc.* **39**: 1-37.

Semikhatov, M.A. Gebelin, C.D., Cloud, P., Awaramik, S.M. and Benmore, W.C. 1979. Stromatolite morphogenesis - progress and problems. *Can. Jour. Earth. Sci.***16**: 992-1015.

Thraikill, J. 1976. Speleothems, p. 73-86. In: *Stromatolites,* (Ed. Walter, M. R.), *Developments in Sedimentology* **20**. Elsevier, Amsterdam.

Walter, M.R. (Ed.) 1976. *Stromatolites* (*Developments in Sedimentology*) 20. Elsevier, Amsterdam.

Walter, M.R. 1977. Interpreting stromatolites. *Am. Sci.* **65**: 563-571.

Walter, M.R. 1996. Old Fossils could be fractal frauds. *Nature,* **383**: 385-386.

Walter, M.R., Grotzinger, J.P. and Schopf, J. W. 1993. Proterozoic Stromatolites, p. 253-260. In: *The Proterozoic Biosphere. A Multidisciplinary Study* (Ed. Schopf, J.W.), Cambridge University Press. New York.

Zachariah, J.K., Srinivasan. R., Gopalana, K. and Sharma, M. 1996. Pb isotopes systematics of Tadapatri and Vempalle dolomites and Pb-Pb age of Cuddapah sedimentation. In MSC abstract.

Manuscript Accepted September 1998

EXPLANATION OF PLATES

Plate I

1. Cyclic pattern of ministromatolites from the Vempalle Formation of the Cuddapah Supergroup. Note that the stromatolites are very small and bulbous in lower part and show erect columnar branching and are dendritic in the middle part. The upper part shows the broken columns indicating an agitated environment that eventually restricted the columnar growth. BSIP Specimen number 37750.

2. Note the major cycles of growth patterns of the ministromatolites. Wall structure is structure characteristically absent in this specimen. BSIP slide number 11809.

3. Note the two major cycles of growth of ministromatolites depicting the columnar nature and branching pattern. The upper region shows the stratified laminae and crenulated algal mats. BSIP specimen number - 37080.

4. Plan section of ministromatolites. Diagrammatic representation is shown in Fig.-2 BSIP specimen number 37751.

Plate II

1. Ministromatolite from the Vempalle Formation exposed in near Kadiri district Anantapur, A. P. India. Note the columnar nature and dendritic branching pattern. Scale =2mm. BSIP slide number 11810.

2. Block shown in fig.-1 is enlarged. Note the alternating light and dark laminae and diffused pigment layer Scale = 1 mm. BSIP slide number - 11810. Note also the recurring stacking of laminae thicknesses in adjacent columns - an indication of second growth.

3. Ministromatolite from the Vempalle Formation. Note the erect, subparallel, closely spaced columns. Branching pattern and dendritic nature. White areas show mosaic of dolomite. Scale = 2 mm. BSIP slide number - 11812.

4. Enlargement block of fig.-3 Showing the subparallel nature of branching and mosaic dolomite. Scale = 5 mm. BSIP slide number - 11812.

5. Ministromatolite in hand specimen. Note the bulbous nature of columns, originating from stratiform structure. Scale = 1 cm. BSIP specimen number -37753.

6. Enlargement of fig. - 4 showing mosaic dolomite and light and dark laminae. Scale bar = 5 mm., BSIP slide number - 11812.

Plate III

1. Stratiform and columnar ministromatolites from the Vempalle Formation Cuddapah Supergroup. Scale = 1 cm., BSIP specimen number - 37753.

2. Ministromatolites from the Vempalle Formation . Note the small protuberences of stromtolites from the stratiform structure and columnar stromatolites. Scale = 5 mm. BSIP slide number - 11811.

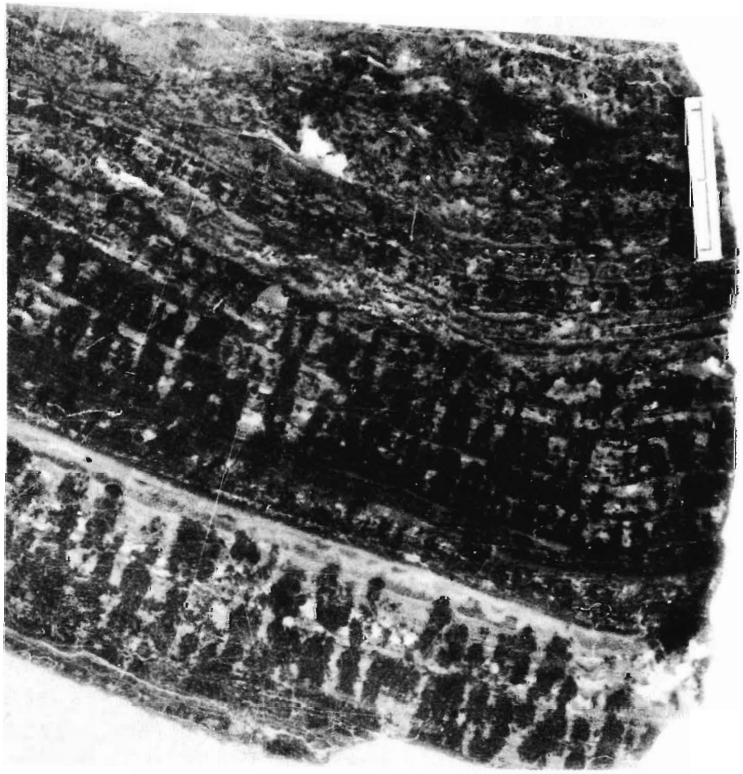
3. Smaller block of Enlargement of Plate - II fig.3 showing the wall structure and mosaic dolomite in the ministromatolite columns. Scale = 5 mm. BSIP slide number - 11812.

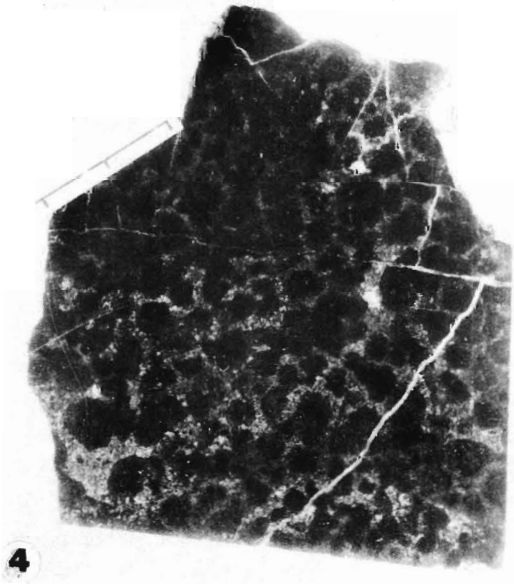
4. Regular banded type of microstructure of ministromatolite showing alternating light and dark laminae. BSIP slide number - 11810.

5-7. Details of radial fibrous fabric of ministromatolites. Gradual enlargement to show radial fabric. Note the silicified radial fibrous fabric in fig. 6 & 7. BSIP specimen number - 37752.

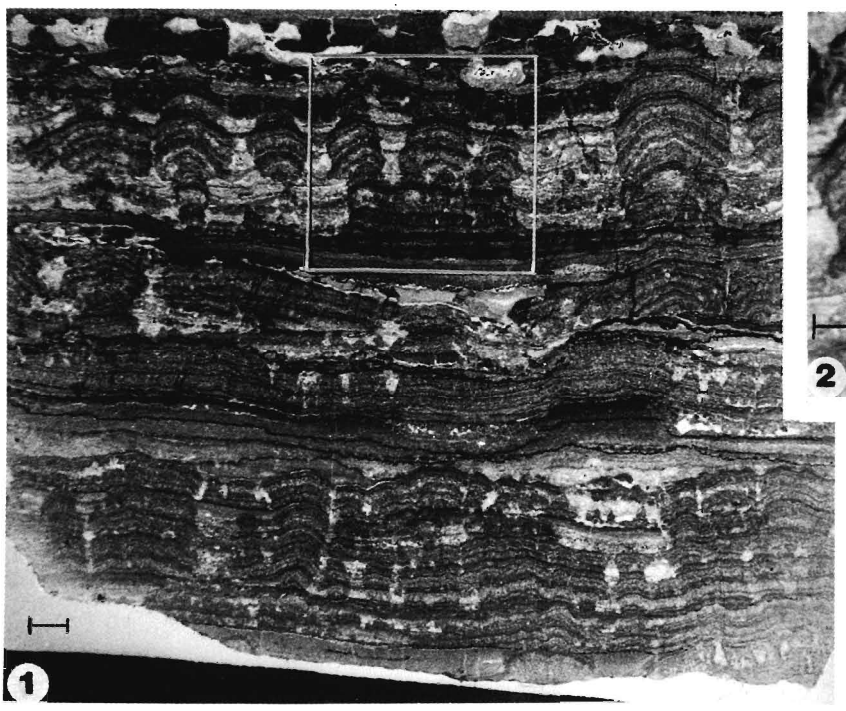
1

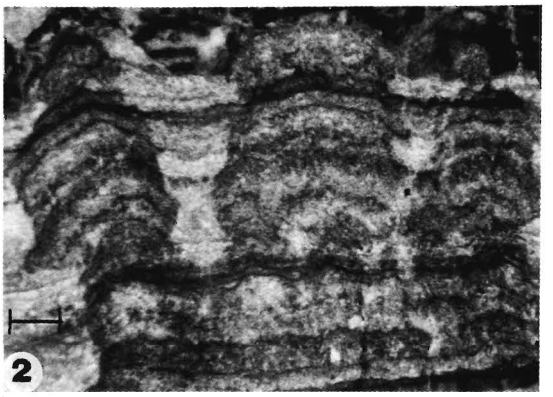
2

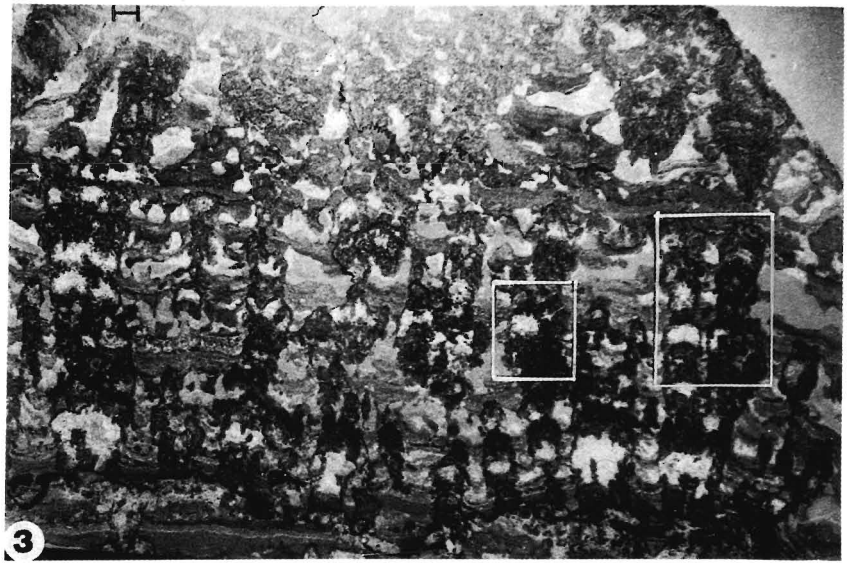


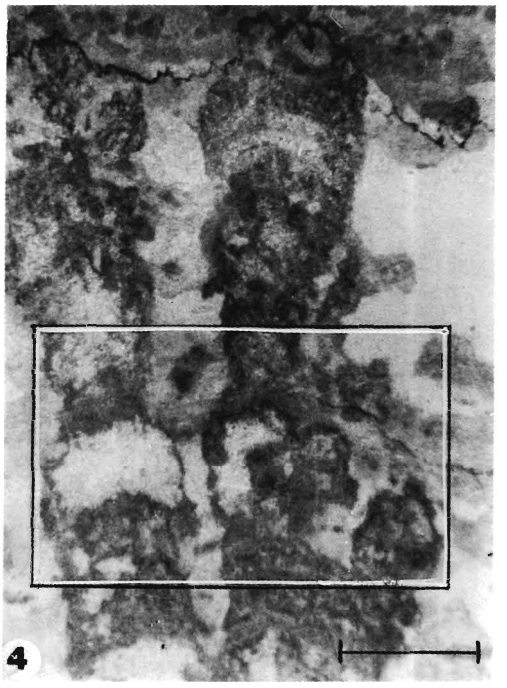


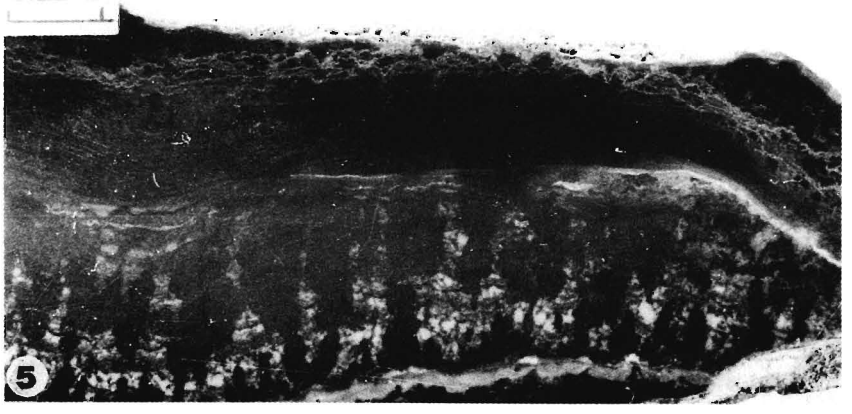
4


1

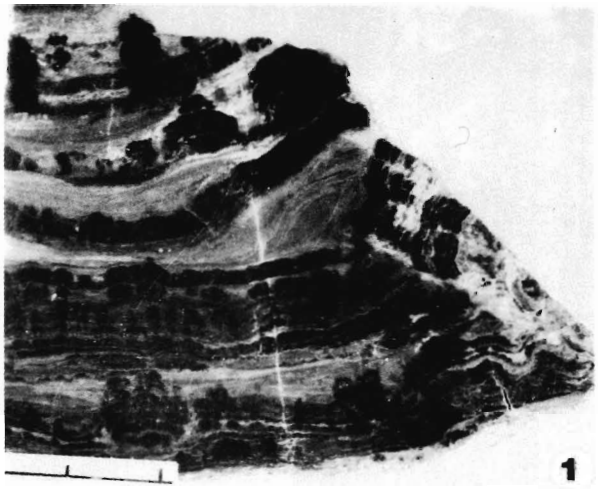

2

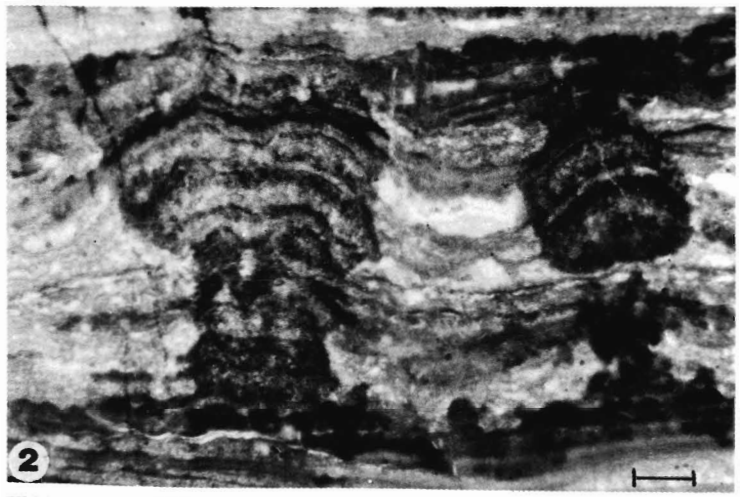

3

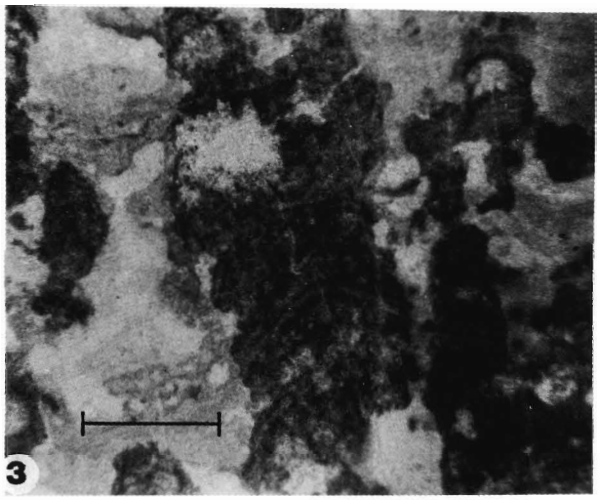

4

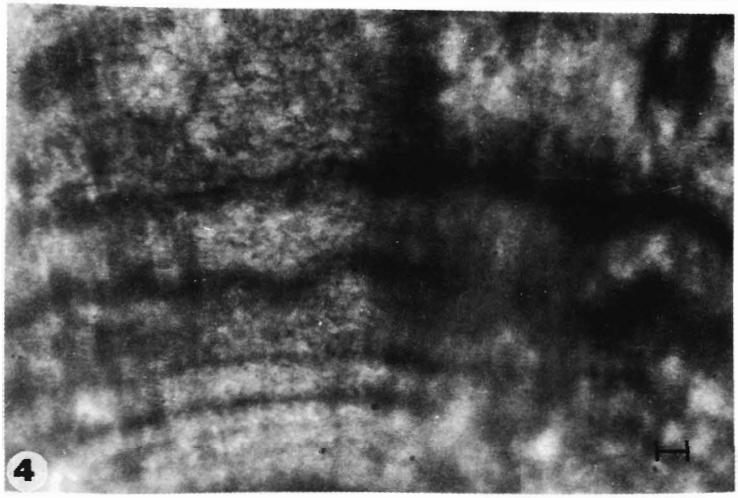

5

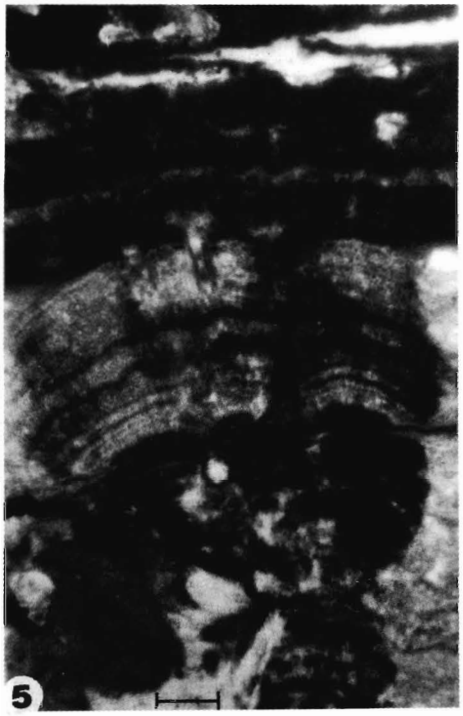

6

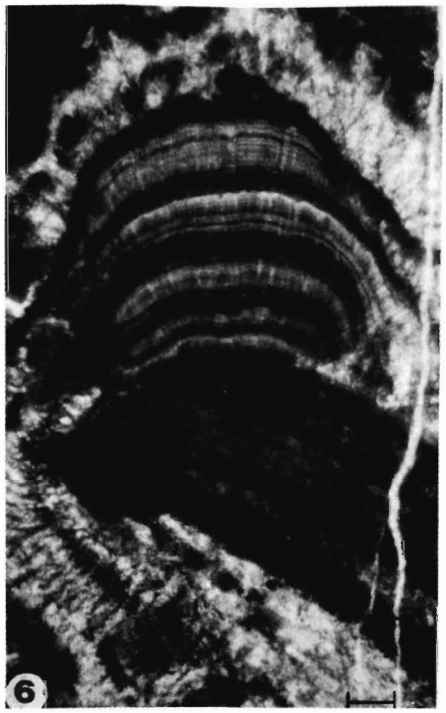


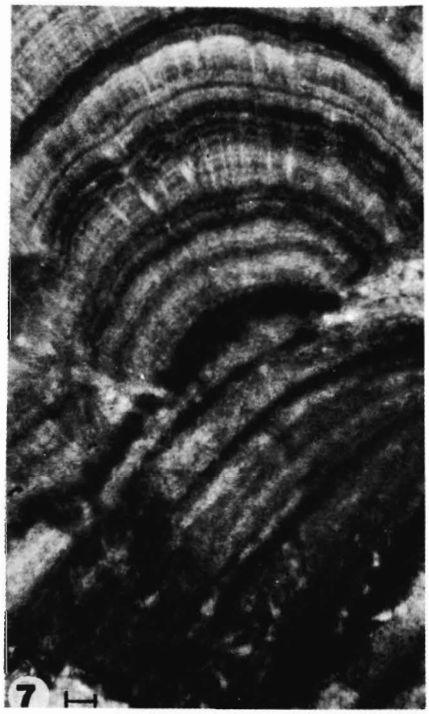












SHARMA AND SHUKLA